RF Compression & Frequency Control for an FFAG Muon Accelerator

Draft 1

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Abstract

1   Introduction

The following note describes an RF Compression and control system designed for a Fixed Field Alternating Gradient (FFAG) Muon Accelerator, but the concept could have application for Pulse Compression in any low frequency RF System.

In conventional synchrotrons, the ring magnetic field is ramped up as the energy is increased by the RF cavities in the ring. This is satisfactory if the required rate of acceleration is moderate. But higher rates of acceleration can be required for high currents (eg for Boosters, Spallation sources, FEL drivers, and particle 'factories'; and also for muons, because acceleration must be accomplished before they decay (life time 2 μsec $\times$ γ). For such higher rates of acceleration, there are only 3 options: A linac, a recirculating linear accelerator, and an FFAG accelerator If a high repetition rate (for high currents or FFAG acceleration

1.1   FFAG's

FFAG Acceleration involves the use of a ring lattice with a very large momentum acceptance (of the order of a factor of 3 or more). Acceleration takes place in many turns about the ring, without any change in the magnetic fields. A cyclotron is an example of Fixed Field Accelerator, and a sector focused cyclotron uses alternating gradient focusing, and is thus an example of an FFAG. In such a cyclotron, although the field remains constant, the rotation time, and thus the required RF frequency varies monotonically with energy. In Flexible Momentum Compaction (FMC) lattices, the variation of frequency with energy can be removed at some central value of energy, but, at least in current designs, there remains a second order variation of frequency (see fig 1).
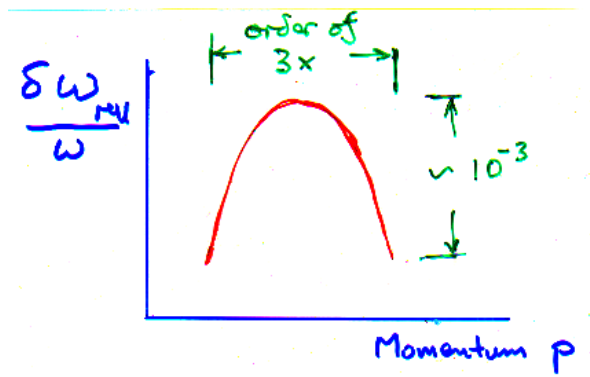

Fig 1 Revolution Freq. vs. Momentum for a nominally isochronous FFAG.

Even larger frequency variations (of the order of 10^{-2}) are required if sig-

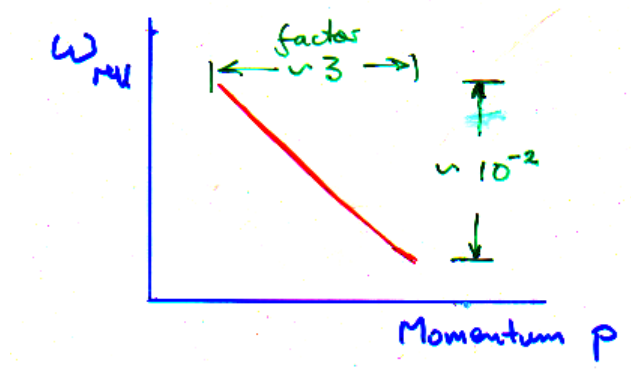nificant synchrotron oscillation is required.

Fig 2 Revolution Freq. vs. Momentum for a non-isochronous FFAG.

These frequency variations (either $\approx 10^{-3}$ or $\approx 10^{-2}$) must occur in a very short time interval (10-30 μ sec), as the energy is increased in a relatively small (of order 20) turns. It is thus impractical to adjust the cavity tune by mechanical means.

1.2   frequency shifting

The most promising method to slew the resonant frequency on the required time scale appears to be to use a weakly coupled ferrite, with applied pulsed magnetic field over the ferrite to modify its effective μ. The design of such a weakly coupled ferrite to adjust the frequency forms the first component of this study.

There is, however, an unfortunate consequence of the use of such ferrites. The cavity will become more lossy; i.e. will have a relatively low Q. As a consequence, the cavity will have to be filled rapidly using very high RF power, unless the rf power can be stored in a separate high Q caviry and transfered into the acceleratibng cavity just before it is used. This is then a form of pulse compression.

1.3   RF pulse compression

The solution to this problem forms the second part of the study. It would involve a second use of the ability of the ferrite to shift the resonant frequency. The accelerating cavity would be weakly coupled to a second high Q (possibly super-conducting) storage cavity. The initial resonant frequencies of the two cavities would be slightly different, leading to two steady state (Eigen) modes at two different frequencies: 1) near that of the storage cavity with most of the field in that cavity, and 2) near the frequency of the accelerating cavity with most of the field there. The RF power source would be coupled into the storage cavity (see fig 3).
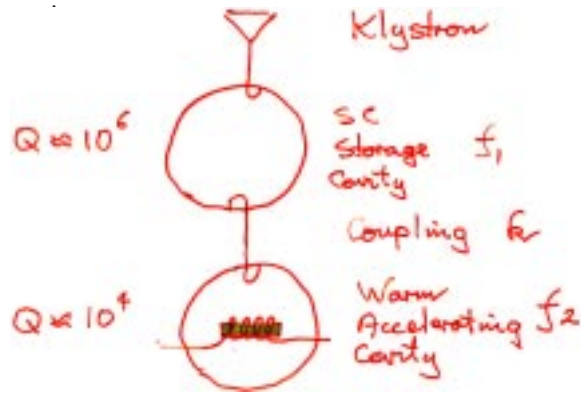
Fig 3.   Concept

   The RF power source would be coupled into the system and the driven at
the first Eigen frequency. The system will then fill with most of the field in the
storage cavity and relatively small losses. After the system is full, the frequency
of the accelerating cavity is lowered (by lowering the magnetic field on the
ferrite), and made to first equal and then fall below the resonant frequency of
the storage cavity. If the frequency swing occurs sufficiently slowly, then the
power will remain in the same Eigen mode, but that mode will be modified so
that the power ends up being mainly in the accelerating structure (see figure
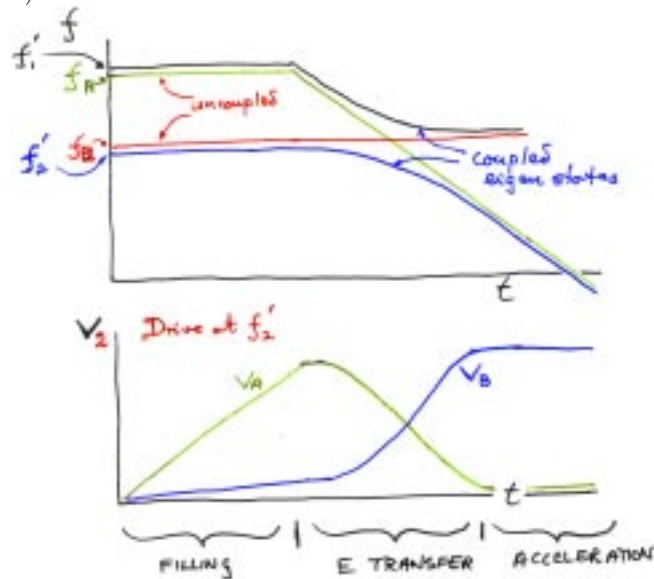4).

Fig 4.   Time development

In this way, the losses remain low during the filling, allowing a relatively long fill time and low RF power. The ferrite is then used to shift the power into the accelerating cavity, where it remains for only a short time, and can adjust the frequency in that cavity as required for the acceleration process.

2   Study Parameters

case		a b	c d
μ Energies	GeV	2-8	8-20
Nominal frequency	MHz	200	200
df/f		10^{-2} 10^{-3}	10^{-2} 10^{-3}
fill time	μsec	1000	1000
acceleration time	μsec	10	30

3   Ferrite frequency control

If a ferrite ring were inserted into an accelerating cavity along the magnetic field lines (fig5a), then the ferrite would saturate under the RF fields and would be very lossy. If it were introduced at right angles to the filed lines (fig 5b) then it would not saturate, but the frequency shift would be small. There are probably many solutions, but that proposed to be studied here is the introduction of a ring of ferrite placed a short distance along the beam pipe (fig 5c) where the RF field strength can be limited so that a good frequency shift is achieved without saturation.
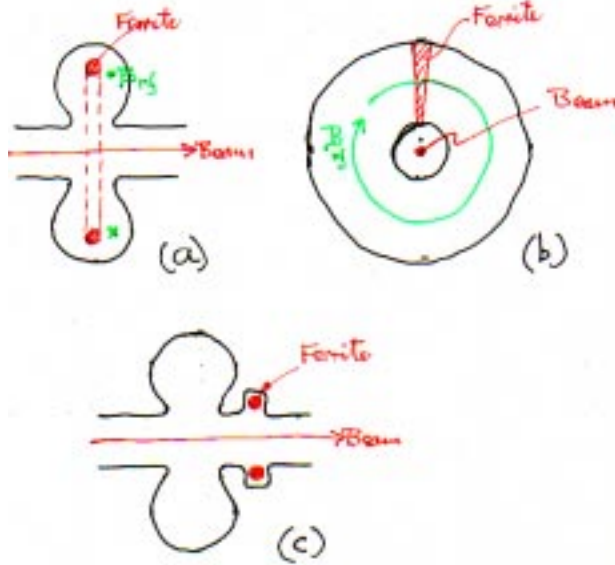

Fig 4. Ferrite coupling options in the cavity

The study will calculate the frequency shifts and losses as a function of the ferrite type, the position of the ferrite along the beam pipe, and on the ferrite cross section.

4   Power storage and transfer

An approximate equivalent circuit of the two cavity system is shown in figure 6. A time dependent computer code (such as PSPICE) will be used to study the performance of the system, including transient effects when the transfer is induced over shorter time periods.
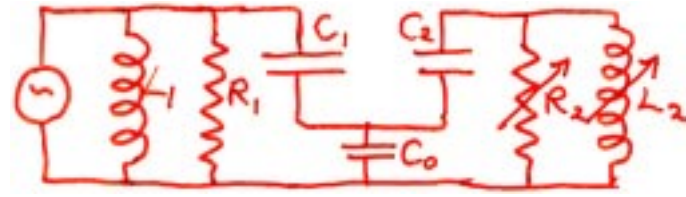

Fig 6.   Equivalent Circuit

5   Conclusion